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FINAL PROGRESS REPORT - GRANT HE 05977-02
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Title: Experimental Construction of an Auxiliary Ventricle

Investigator: Adrian Kantrowitz, M.D.
Surgical Research Laboratory
Maimonides Hospital
4802 - Tenth Avenue
Brooklyn 19, N.Y.

Summary Statement

Our primary aim-harnessing the diaphragm's motor power to propel blood in the arterial system of dogs--has been realized. Methods were developed for: (1) mobilizing a hemidiaphragm with its nervous and vascular supply intact; (2) repairing the defect created; (3) wrapping the mobilized muscle around the heart or aorta; (4) designing an electronic circuit to pick up the ECG and synchronize the stimulus with it; (5) stimulating the auxiliary ventricle through a timing device triggered by the QRS complex of the ECG, so that the stimulus and ECG signal could be synchronized; (6) measuring the effects of the auxiliary ventricle on diastolic pressure in the carotid and femoral arteries.

Results

In acute experiments, the dog's left hemidiaphragm was mobilized, keeping the major blood supply and left phrenic nerve intact, then folded into a rectangle and wrapped around the distal thoracic aorta. Wire electrodes were implanted in this "auxiliary ventricle" and stimuli applied. The stimulator, triggered by the QRS complex of the ECG via a timing device, could be synchronized with the ECG signal. Low-voltage stimuli caused a significant rise in diastolic pressure of the carotid artery, and mean diastolic pressure in this vessel was 15-20 mm. Hg higher during augmentation. In chronic experiments the diaphragmatic defect was repaired with a Dacron prosthesis. Carotid and femoral artery pressures were taken and ECGs recorded simultaneously in selected dogs up to 7 months postoperatively. In those sacrificed within 100 days

* Including 3-month extension period for orderly termination of NIH support for this project.

the prosthesis was well anchored and appeared to have functioned well.' The auxiliary ventricle in chronic dogs contracted in response to almost the same voltage as in the acute animals. Up to 105 days postoperatively, stimulation caused a significant rise in diastolic pressure in the carotid artery, and mean diastolic pressure in this vessel rose as much as 8 mm. Hg. Blood pressure changes during augmentation at four and seven months were much more marked in the femoral artery than in the carotid. At times femoral systolic pressure dropped 20 mm. Hg and mean systolic 15 mm. Hg; diastolic pressure rose 25 mm. Hg, and mean diastolic 15 mm. Hg with low-voltage stimuli. The auxiliary ventricle studies are continuing with use of a Silastic bulb instead of a hemidiaphragm to augment myocardial function.

These studies concerned with augmenting myocardial function led to the development (jointly with the Electronics Laboratory of the General Electric Company) of a controllable, electronic cardiac pacemaker which has been implanted in over 200 patients in our hospital and elsewhere. All were suffering from complete heart block, and the majority had intractable Stokes-Adams seizures. Results to date are considered encouraging. This pacemaker has a fixed minimum rate and can also be controlled externally for optional use during periods of unusual physical stress. The basic circuit is a PNPN complementary transistor configuration connected in a relaxation oscillator. The external circuit operates in essentially the same way. The implanted pacemaker consists of 5 batteries, 2 transistors, 3 resistors, and 1 capacitor--all chosen for high reliability, small size and weight, and low power drain. The entire unit weighs 4 oz. and measures $1\frac{1}{2}$ x 4 x 6 cm. It is potted in an epoxy-resin and sheated in Silastic (Teflon was used in the earlier models). The rated current capacity of presently available batteries suggests about five years' operation. Any decrease in voltage will be readily apparent from the patient's altered pulse rate. The load terminals are connected to Teflon-coated electrodes sutured deep in the myocardium and run through a subcutaneous tunnel to the unit itself, which is placed in an abdominal pocket and sutured firmly to the anterior rectus sheath. None of the deaths were attributed to failure of the electronic circuitry. Wire breakage or dislodgment, which occurred in several cases, was usually repaired without resorting to another thoracotomy. We are now discussing with General Electric engineers a modification of the external control circuit to permit its rate to respond to that of the atrium.* If this proves feasible, the new circuit will be tested in our own series of

* Related to projects supported by Grant H-6510.

patients to determine whether synchronous pacing is more desirable than an arbitrarily set ventricular rate.

The effectiveness of direct muscle stimulation, attested by the cardiac pacemaker, has influenced our research focus to some extent. We are still attempting to develop an electrode for long-term nerve stimulation, however, since it would have wide therapeutic application in conditions not amenable to the simpler method of direct stimulation.

A group of exploratory studies begun under Grant HE-5977 suggest the far future possibility of substituting electronic directions for nerve impulses destroyed in patients with upper motor neuron injuries. A taped program was recorded during manipulation of a specially built, jointed wooden model of a dog's hind leg. On playing this program into the animal, electrodes implanted in the leg enabled it to reproduce the same crude movements that had been prearranged on the model. The next step was preparation of a four-part stimulus with the aid of a tape recorder which enabled a human paraplegic to rise from a sitting position, stand a few minutes, and sit down in response to programmed directions. The stimulus was applied through the skin via electrodes implanted at motor points on the vastus and gluteus muscles of both legs. In a later study the knee joint in a paraplegic was made to assume a desired angle and then return to the floor by a simple servomechanism, which controlled the leg's rectus femoris muscles. At present we are designing a servomechanism to control both the rectus femoris muscle and its antagonist, the hamstring muscle group, driving the knee in two directions.

Early experiments on electronically stimulated, coordinated limb movements in dogs were reported at the 46th Clinical Congress, Forum on Fundamental Problems, American College of Surgeons, in October 1960.

Publications of Research Supported Partially or Wholly by U.S. Public Health Service Grant HE 05977-02

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Film

Kantrowitz, A. and R. Khafif: Electronic Production of Coordinated Limb Movements.